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Transport modelling in the context of the 'predict and provide' paradigm

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The central concern of this paper is why the traffic-increasing effect of road capacity expansion (induced traffic) is still frequently ignored when preparing decision-support material for proposed infrastructure investments. Earlier research has pointed at ignorance or technical difficulties as likely reasons. This paper offers an additional explanation. Based on an investigation of the opinions of transport modellers, consultants, transport planners and politicians concerning the usefulness, shortcomings and application of forecasting models in transport planning, this paper suggests that transport model forecasts are used in project evaluations primarily to throw light on where and when to build a proposed road infrastructure, not for assessing whether to build it. Since induced traffic is usually not differing so much between the different 'build'-alternatives, the errors caused by omitting induced traffic in the models are accepted. This way of framing the decision problem is often associated with what has been termed the 'predict and provide' paradigm.

Keywords: *induced traffic, modelling, predict and provide, planners, consultants, qualitative interviews, survey.*

1. Introduction

Traffic forecasting plays a key role in contemporary transport policy, planning, and engineering. Traffic models are used not only to optimize the design of proposed projects, but also to produce key input data for environmental impact assessments and cost-benefit analyses, such as expected time savings, safety effects and changes in pollution and noise levels. Needless to say, it is of vital importance to informed decision-making that the model outputs are based on valid assumptions.

Theories of transport economics and transport geography as well as a number of empirical studies in Europe and the USA indicate that road development facilitating higher travel speeds will release latent demand and hence attract more car drivers. An immediate congestion relief is sometimes observed, but often this is only temporary (Downs, 1962; Thomson, 1977; SACTRA, 1994; Hills, 1996; Mogridge, 1997; Noland and Lem, 2002; Næss, Mogridge and Sandberg, 2001;

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Goodwin and Noland, 2003; Litman 2012). If the strategy of combatting congestion by increasing road capacity is chosen, the capacity must repeatedly be increased in order for the expected benefits to materialize, following what has been termed the 'predict and provide' approach (Owens, 1995).

In line with Schmidt and Campbell (1956, quoted from Cervero, 2001:4), we define *induced traffic* as 'the added component of traffic volume which did not previously exist in any form, but which results when new or improved transportation facilities are provided'. This includes vehicle traffic resulting from increased distances between origins and destinations, changes in travel routes, changes in travel modes as well as changes in trip frequencies (Hills, 1996). Diverting of traffic from one route to another (apart from any difference in route length) is not included in the concept of induced traffic as we use it, although such diversion may contribute to the rise of congestion on a new or expanded road scheme and is included in the notion of generated traffic (Litman, 2012). Induced traffic as understood here should be measured in terms of vehicle kilometres travelled (VMT), although in empirical studies simpler approaches such as traffic counts at selected screen-lines have often been applied (Cervero, *ibid.*)

The magnitude of induced traffic in a particular situation depends on the specific situation at hand. Usually, more traffic tends to be induced by road capacity increases in congested areas where there is considerable suppressed demand (typically in urban contexts) than in areas where congestion does not at the outset make up any deterrent against driving (e.g. in rural areas). Road improvements will, however, often induce traffic growth also in non-congested areas; this is, for example, likely to happen if the new road allows faster driving (e.g. with a higher speed limit) and thus reduces travel time. Reflecting the various contexts at hand, a number of investigations in the United Kingdom and the USA indicate that a 10% increase in road capacity (measured in the number of kilometres of driving lanes in each direction within a traffic corridor) seems to result in traffic increases of around 3 – 5% in a short term and between 5 and 10% in a long term (Noland and Lem, 2002:16; Litman, 2012:9). In a study of 45 Danish road projects, Twitchett (2013) found the immediate induced traffic (i.e. within the first year after opening) to be on average 9 %, with lower-than-average figures for bypasses and highways and higher-than-average figures for motorways and especially for fixed-link motorway bridges replacing ferries. For the few Danish projects where traffic counts were available over a longer period after opening, the amount of induced traffic after four years was typically found to be twice or three times as much as in the first year after opening (Twitchett, *ibid.*)

Despite the fact that induced traffic has been understood theoretically for at least one-and-a-half centuries (Schram and Hjort 1840) and demonstrated empirically in several studies over the latest eight decades (Christiani and Nielsen et al. 1936; Schmidt and Campbell 1956; Ladd 2012), disregard or severe underestimation of induced traffic in the forecasting models used in infrastructure project evaluation is a quite widespread phenomenon internationally (Button and Henscher, 2001; Marte, 2003; Goodwin and Noland, 2003; MOTOS, 2007; Litman, 2012). This is also the case in Scandinavia. In Denmark, induced traffic has usually been underestimated or totally ignored in local and regional traffic models (Nielsen and Fosgerau 2005; Næss, 2011; Twitchett, 2013; Andersen, 2013), which has led to a general underestimation of traffic on new roads (Nicolaisen, 2012). The main exception is the so-called Ørestadens Trafik Model (OTM), covering the Greater Copenhagen Area.

The situation in Norway and Sweden does not seem very different (Minken, 2005; Welde and Odeck, 2011; UNITE, 2011). Omission of induced traffic can lead to serious bias in the assessments of environmental impacts as well as the economic viability of proposed road projects, especially in situations where there is a latent demand for more road capacity (for an illustrative example, see Næss, Strand and Nicolaisen, 2012).

Omission of induced traffic in the traffic models implies that the forecasted traffic volume will be the same for the road-building alternatives as in the case where no new capacity is added.

Neglect of induced traffic can thus also lead to overestimated forecasts for the 'no-build' (or zero) alternatives (Næss, 2011). This may happen if the future traffic volumes are estimated on the basis of trend extrapolation (as in several regional/local models used until recently or still in use in Denmark, such as the so-called Aalborg model), since observed trends in traffic growth are often themselves partly a result of prior capacity expansions. Neglect of induced traffic will then mean that the deterrent effects of congestion on future traffic growth for the zero-alternatives are ignored, resulting in unrealistically high forecasts for the future traffic volumes in cases where no new capacity is added.

Different explanations for omission of induced traffic have been put forth. The philosophy that has for several decades underpinned the process of traffic forecasting is the so-called 'predict and provide' paradigm, according to which demands are projected, equated with need and met by infrastructure provision to the extent that funding can be made available (Owens, 1995). Omission of induced traffic in the traffic models has often been associated with this paradigm.

In academic transport research, neglect of induced traffic in traffic modelling has frequently been considered as reflecting an assumption of inelastic relationship between road capacity and car travel demand (Cerwenka and Hauger, 1998, Noland and Lem, 2002). This does, however, not always fit well with empirical evidence (Andersen 2013; Goodwin 1998). Induced traffic was not at the outset included in the standard computerized four-step transport models, and due to convenience and a certain path dependency established as the use of these models was sustained, it became difficult to modify what was seen as a tested procedure (Goodwin, 1998). It is, however, possible to include induced traffic in traffic models (SACTRA, 1994; Litman, 2012).

Based on an investigation of the opinions of Scandinavian transport modellers, consultants, transport planners and politicians concerning the usefulness, shortcomings and application of forecasting models in transport planning, this paper aims to illuminate why model-based traffic forecasts are generally considered important and valuable despite recognized limitations in their ways of dealing with induced traffic. The structure of the paper is as follows: In the next section (2), the research design and methods of the study will be outlined. Section 3 presents the key findings from qualitative interviews and a questionnaire survey involving planners, modellers and politicians. A brief discussion and some concluding remarks are given in the last section (4).

2. Research design and methods

The study on which this paper is based was carried out as part of a larger research project, 'Uncertainties in transport project evaluations' (UNITE), conducted jointly by the Danish Technical University, Aalborg University and a number of sub-contractors. The main data sources of the paper are interviews and a questionnaire survey.

16 qualitative interviews were carried out from 2010 to 2012 with key stakeholders in the production or use of traffic forecasts as decision support: model developers, consultants, traffic planners, transport-sector bureaucrats involved in policy-making at national or local level, and politicians with transportation policy as a field of responsibility (e.g. members of the National Parliamentary Committee on Transport). The selection of interviewees was made in order to gain information from persons representing different roles in the forecasting process. Apart from two Swedish researchers involved in the development of what had been characterized by other interviewees as 'state-of-the-art' transport models, all the interviewees were from Danish institutions. The reason for the Danish focus was mainly practical, since all interviews were conducted by researchers located at Aalborg University. The interviews lasted from one to three hours and were tape-recorded and subsequently transcribed.

The questionnaire material is based on a survey carried out in 2010 among the same categories of stakeholders. Many of the questions of the questionnaire were formulated as statements with

which the respondents were asked to indicate their extent of agreement along a five-point Likert scale. Distinct from the interviews, the questionnaires covered a broader Scandinavian context. Invitations to respond to the web-based questionnaires were distributed to transport-related research units at universities, transport units in consultancy firms, road and rail directorates, transport sections in regions/municipalities, transport/environment-related NGOs, and parliamentary transport committees in Denmark, Norway and Sweden. The mail recipient at the contact address was asked to forward the invitation mail to those employees or elected officials for whom the questionnaire would be relevant. For each country, national-language versions of the questionnaire were provided. After having sent one set of reminder mails, we received in total 453 completed questionnaires. Roughly two fifths of the respondents were from Denmark, another two fifths from Norway and the remaining 20% from Sweden.

Additionally, during the preparation of this paper, some follow-up e-mail questions were sent in the summer of 2013 to twelve of the interviewees (i.e. those interviewees considered as the ones most closely involved in model-based infrastructure planning), asking particularly about the usefulness of traffic models for different purposes. Nine of the interviewees responded, answering four questions with closed answer alternatives (Likert-scale) as well as writing qualitative elaborations of these answers.

In addition to interviews and questionnaires, the paper also draws on documents where information has been found about, respectively, forecasting inaccuracy for Danish, other Scandinavian and British road projects and the extent to which Danish traffic forecasters and transport modellers have been aware of the phenomenon of induced traffic. Each of these two main categories of information were first systematized and analysed in two Ph.D. theses (Nicolaisen, 2012; Andersen, 2013).

The interview material has been analysed based on two different approaches. First, a qualitative content analysis was conducted, following an interpretation scheme tailor-made for the present study. This scheme comprised four detailed research questions which we, as researchers, tried to answer, based on the information given by the interviewees (first interpreting the statements in each separate interview and then synthesizing across the 16 interviews). Second, selected formulations used by the interviewees in their description and discussion on the practice and role of traffic forecasting were scrutinized, inspired by methods of critical discourse analysis (CDA) (Wodak and Meyer, 2009) and drawing in particular on the dialectical-relational (Fairclough, 2009) and the discourse-historical (Reisigl and Wodak, 2009) approaches to CDA.

3. Findings

In this section, the key findings of the study will be structured according to topics. Under each topic, findings from the qualitative interviews as well as from the questionnaire survey will therefore be presented. The material will be grouped into the following three broad topics: purposes of using traffic models, awareness about model uncertainties and shortcomings, and 'predict and provide' as a tacit underlying assumption. A more detailed account of the conclusions from the individual interview interpretations on which the following analysis is based can be found in the Appendix.

Key results from the questionnaire survey are displayed in Table 1, showing the proportions among the total sample of respondents as well as within particular groups of respondents (researchers, consultants, civil servants/clients, and politicians) who have expressed that they agree and disagree fully or partially with the various statements listed. Some of the respondents are having more than one of the roles indicated by the column headings; for example, some are both consultants and researchers or both politicians and consultants. Therefore, the sum of the number of respondents in the four sub-groups of respondents (477) is higher than the total number of respondents (453).

3.1 Purposes of using traffic models

The respondents of the questionnaire survey generally find model-based traffic forecasts important and valuable for several reasons. There is generally strong support of the statements that traffic forecasts are important in order to gain knowledge of future traffic conditions (93 % fully or partially agree; cf. Table 1); that traffic models are important in order to get an overview on complex systems (89 % fully or partially agree); and that traffic forecasts are important in order to design the details of a project (78 % fully or partially agree), with relatively small variations between the different groups of respondents. A clear majority among the respondents also believe that traffic forecasts provide objective information on the traffic impacts of a transport project (69 % fully or partially agree), although the support of this statement varies somewhat between researchers (64 % support) and consultants (81 % support), with politicians and civil servants/clients in-between.

Three out of four respondents think that traffic forecasts have a high influence on what projects will be approved, but there is quite some variation between respondent groups, with the highest support of the statement found among politicians (83 % fully or partially agree) and the lowest among researchers (68 % fully or partially agree). There is, however, also a considerable proportion of respondents who think that traffic forecasts are often used to justify projects for which a political decision to build has already been taken (56 % fully or partially agree, with moderate variations between respondent groups).

The interviewees of the qualitative part of the study also consider the preparation of decision support about transport infrastructure projects to be an important purpose of traffic modelling. Although model-based forecasts may not be so important for identifying the need for a new infrastructure project, they are important to legitimize project implementation and as a base for arguments to this end, as illustrated in the following statement by a politician:

They don't matter so much at the early stage. But they become important if you are to proceed with an idea. Then they are decisive for the acceptance of the arguments. (Former city council member and chairman of the municipal transport committee, in interview November 2010.)

According to one interviewee, planners need the quantitative figures provided by the traffic models to be able to communicate on a level that is useful for the politicians. Why the communication with politicians should be on a quantitative level is not specified by this interviewee, but a plausible interpretation is that quantified information is perceived by the politicians to be more objective and reliable than more qualitative assessments (Porter, 1996). Some interviewees also emphasize quantitative, model-based traffic forecasts as necessary input to the mandatory cost-benefit analyses and environmental impact assessments of governmental transport infrastructure investments.

In particular, model-based forecasts are considered helpful in order to compare different alternative layouts of a proposed project:

Models are just [producing] a mathematical description of people's behaviour, which you can apply particularly to compare alternatives in a good manner - in a good and consistent way. You can use models in particular when comparing alternatives, because the calculations for both - or all three or whatever - alternatives are based on the same assumptions, [enabling you] to say: Which one is the best, given these assumptions? (Consultant, Denmark, in interview July 2010)

Table 1. Proportions of respondents agreeing and disagreeing fully or partially with various statements about induced traffic, forecasts and traffic models

Statement	Proportions fully or partially agreeing and disagreeing (valid percent)				
	All respondents (N = 453)	Researchers (N = 51)	Consultants (N = 83)	Civil servants and clients (N = 170)	Politicians (N = 173)
Traffic forecasts are important in order to gain knowledge of future traffic conditions	Agree: 93% Disagree: 3% (N=440)	Agree: 98% Disagree: 2% (N=51)	Agree: 96% Disagree: 2% (N=81)	Agree: 93% Disagree: 4% (N=168)	Agree: 92% Disagree: 2% (N=167)
Traffic models are important in order to get an overview on complex systems	Agree: 89% Disagree: 3% (N=435)	Agree: 88% Disagree: 2% (N=51)	Agree: 95% Disagree: 1% (N=81)	Agree: 92% Disagree: 3% (N=166)	Agree: 82% Disagree: 4% (N=165)
Traffic forecasts are important in order to design the details of a project	Agree: 78% Disagree: 9% (N=438)	Agree: 73% Disagree: 10% (N=51)	Agree: 88% Disagree: 6% (N=81)	Agree: 78% Disagree: 13% (N=167)	Agree: 78% Disagree: 7% (N=167)
Traffic forecasts provide objective information on the traffic impacts of a transport project	Agree: 69% Disagree: 23% (N=438)	Agree: 64% Disagree: 8% (N=50)	Agree: 81% Disagree: 7% (N=80)	Agree: 70% Disagree: 21% (N=166)	Agree: 70% Disagree: 22% (N=167)
Traffic forecasts are often used to justify projects for which a political decision to build have already been taken	Agree: 56% Disagree: 24% (N=418)	Agree: 60% Disagree: 25% (N=48)	Agree: 62% Disagree: 27% (N=74)	Agree: 55% Disagree: 22% (N=155)	Agree: 51% Disagree: 27% (N=151)
Traffic forecasts have a high influence on what projects will be approved	Agree: 75% Disagree: 13% (N=439)	Agree: 68% Disagree: 24% (N=50)	Agree: 70% Disagree: 15% (N=80)	Agree: 71% Disagree: 15% (N=164)	Agree: 83% Disagree: 9% (N=169)
Traffic forecasts are often biased and therefore misleading	Agree: 37% Disagree: 40% (N=429)	Agree: 48% Disagree: 40% (N=50)	Agree: 39% Disagree: 38% (N=79)	Agree: 27% Disagree: 47% (N=165)	Agree: 40% Disagree: 36% (N=159)
If forecasts are inaccurate, are they in your experience generally underestimating or overestimating future amounts of traffic for the approved projects?	Underest: 38% Overest: 18% (N=444)	Underest: 18% Overest.: 29% (N=49)	Underest: 17% Overest: 22% (N=82)	Underest: 27% Overest: 21% (N=168)	Underest: 61% Overest: 11% (N=170)
If forecasts are inaccurate, are they in your experience generally underestimating or overestimating future amounts of traffic for the zero alternative?	Underest: 38% Overest: 8% (N=128)	Underest: 7% Overest: 14% (N=14)	Underest: 17% Overest: 10% (N=29)	Underest: 39% Overest: 6% (N=66)	Underest: 53% Overest: 9% (N=34)
Expansion of road capacity in congested areas result in an overall increase in traffic	Agree: 77% Disagree: 11% (N=424)	Agree: 88% Disagree: 6% (N=50)	Agree: 89% Disagree: 3% (N=76)	Agree: 76% Disagree: 8% (N=161)	Agree: 65% Disagree: 22% (N=164)
Traffic models are poor at forecasting the effects of induced traffic	Agree: 61% Disagree: 20% (N=238)	Agree: 59% Disagree: 33% (N=49)	Agree: 68% Disagree: 23% (N=71)	Agree: 61% Disagree: 15% (N=149)	---
Traffic forecasts usually exaggerate the risk of congestion if no new infrastructure is built	Agree: 40% Disagree: 36% (N=403)	Agree: 47% Disagree: 6% (N=45)	Agree: 49% Disagree: 38% (N=72)	Agree: 41% Disagree: 32% (N=144)	Agree: 36% Disagree: 40% (N=161)

Traffic models are considered a basic condition for this purpose, especially as a tool for identifying 'when problems will occur' (i.e. at what time, and where, congestion problems will occur with the assumed traffic growth rate), but also for identifying how different parts of the existing road network would be relieved.

Several interviewees also point at traffic models as a necessary tool in order to get an overview of a complex system, in particular for shedding light on the consequences to other affected variables if one or more of the assumptions fed into the model are changed. One important such exogenously set assumption, mentioned by one of the interviewees, is the presupposed annual traffic growth. The traffic model enables the planners to make 'what if'-analyses where the consequences of varying growth rates in terms of traffic volumes on different links of the road network can be explored.

3.2 Awareness about model uncertainties and shortcomings

The respondents are more divided in their views on whether or not traffic forecasts are often biased and therefore misleading. 37 % of the total sample more or less agree while 40 % more or less disagree, with a relatively large percentage (23 %) expressing a neutral attitude. Researchers are more prone to consider forecasts to be biased (48 %) than among the sample as a whole, whereas the opposite is the case among civil servants and clients (27%). This might indicate a lower awareness about limitations in the models among transport planners and bureaucrats who are not themselves developing or running transport models than among those respondents who have more first-hand experience with modelling.

Apart from the politicians, the remaining respondents were also asked about reasons for potential forecasting inaccuracies. One of these questions explicitly addressed poor ability of models to deal with induced traffic as a potential cause of inaccuracy. On average, more than three out of five respondents (61 %) agreed fully or partially that this was a cause of inaccuracy, with only little variation between researchers, consultants and civil servants/clients. There was also only small difference between respondents whose experience was mainly with road projects and rail projects, respectively. This might seem a bit surprising, since the qualitative interviews indicate that induced traffic is normally included in the forecasts for rail projects while often being ignored in forecasts for road projects.

It is also noteworthy that several of the interviewees consider the inaccuracy caused by omission of induced traffic to be rather modest (see also the next section). This may in some cases reflect a widespread understanding among Danish transport modellers of induced traffic as a much narrower concept than the definition referred to above (cf. Schmidt and Campbell, 1956; SACTRA, 1994 and Hills, 1996). For example, according to one of the leading Danish model developers, 'induced traffic is a result of infrastructure improvements causing the total number of trips to increase. It has nothing to do with changes in travel mode' (Overgaard, 2012). Another example of a narrow conception of the phenomenon of induced traffic is the following statement by one of our interviewees:

The models offer an estimate of the magnitude of traffic relief on the existing road network provided by different line layouts proposed for a new road. Redistribution of existing traffic between different routes is usually the main effect of a [road] building scheme; hence benefits and drawbacks of a project may well be calculated even without calculating changes in the total traffic demand. (Chief consultant in the Danish Road Directorate, in follow-up e-mail communication August 2013 after interview September 2010.)

Here, induced traffic is conceptualized as only including traffic increase on the new road scheme, with no consideration of indirect effects on the surrounding network. The above statement does not take into account that induced traffic must also be expected to occur on the existing road network after the initial relief, contributing to congestion rising again toward the original level⁵.

⁵ It might be argued that congestion would not rise towards the original level fully due to induced demand, since if congestion grew to that level, there would be no further travel time gains and hence no further induced demand. And since a part of the traffic growth is usually reflecting the general, 'background' growth in mobility at a national/regional scale, only a part of the traffic growth leading to a new equilibrium would be induced traffic. While this is true, there are also imaginable situations where induced traffic causes congestion to reach a worse level than before the road capacity expansion. This phenomenon, sometimes referred to as the 'Downs-

Although recognizing the phenomenon of induced traffic, this interviewee does not consider its magnitude to be very significant.

In a similar vein, another interviewee, asked to comment on the likely consequence of replacing one of the two existing car lanes in each direction with separate bus lanes on the only road bridge across the Limfjord sound in central Aalborg, considered that this would have negligible effect on the modal split:

I think you get very, very little shift of traffic from cars to transit by doing this. (Project manager in the transport department of a Danish consultancy firm, in interview June 2010.)

The latter statement is at odds with findings from empirical studies in Scandinavia (Municipality of Trondheim, 2009) and the United Kingdom (Cairns et al., 2002).

On the other hand, some of the traffic planners interviewed recognize that induced traffic may be substantial and consider it to be generally profitable for society since more drivers will then benefit from the improved travel opportunities brought about by road construction, as stated in the following quote:

.... you have to acknowledge that induced traffic occurs ... and in a cost-benefit analysis, the benefits will be underestimated if induced traffic is ignored. ... There are consumer benefits from the induced traffic. At the same time, there are of course also greater environmental impacts, but in the economic analyses they represent a much smaller amount of money. ... if a road is expanded, then the capacity is enlarged by nearly 50%. Traffic has to increase a lot before congestion reaches the same level as before the expansion... I fear that we have overestimated the effect of induced traffic in some of the more recent projects. (Chief consultant in the Danish Road Directorate, in interview September 2010.)

Here, the interviewee admits that neglect of induced traffic entails an underestimation of environmental impacts, but since travel time savings account for a much larger benefit item in the cost-benefit calculation, the omission of induced traffic is still conceived to result in a conservative estimate of the net benefits of the project. The neglect is therefore considered as legitimate.

Omission of induced traffic is thus sometimes depicted as a sort of precaution in order to avoid exaggerating the benefits from travel time saving in the economic project evaluation. While this way of reasoning may be relevant for road improvements in uncongested areas (cf. Welde and Odeck, 2011), induced traffic cannot generally be said to increase the time-saving benefits of a project. In congested transport corridors, induced traffic can, as discussed in Section 1, cause traffic to increase to a level where congestion arises anew and reduces time-saving per driver significantly, compared to the situation if no extra traffic appeared. While most of the questionnaire respondents and interviewees recognize the existence of induced traffic, the fact that such traffic increase can result in new congestion is mentioned by fewer. As shown by Næss, Nicolaisen and Strand (2012), neglect of induced traffic in the cost-benefit analyses of a proposed road scheme in a congested area can lead to severely biased estimates of the economic performance of the project.

Some interviewees hold that congestion resulting from induced traffic is a phenomenon occurring only in the central parts of the Copenhagen area, not in other parts of Denmark. This conception is, however, at odds with the fact that a main argument put forth for the construction of the 3rd Limfjord Crossing in North Jutland, far away from Copenhagen, has throughout the different planning phases been to relieve future congestion. In the case of the moderately congested Frederikssund motorway in the outer parts of Copenhagen metropolitan area (also analysed by Næss, Nicolaisen and Strand, *ibid.*), the inclusion of induced traffic also resulted in a

Thomson paradox', can occur if the initial induced car traffic includes a shift from public to private transport leading to loss of ticket revenues for the transit companies eventually resulting in a reduced level of service. A new modal share equilibrium may then be established at a lower average speed – also for car traffic – than before the road expansion (Mogridge, 1997).

lower net present value than if induced traffic was omitted. Regardless of time-saving benefits, negative environmental impacts will be underestimated if induced traffic is ignored.

Nearly four out of ten (38 %) among the total sample are of the opinion that traffic forecasts, if they are inaccurate, tend to underestimate the future volume of traffic of the approved projects, whereas less than one out of five (18 %) think that the forecasts tend to overestimate the actual volume of traffic. As evident from these figures, a rather high proportion of the respondents either do not feel able to state any opinion or consider that the inaccuracies vary too much to make any particular statement. Among the remaining respondents, the preponderance of conceptions of forecasts as being underestimated is in line with the actual inaccuracies found by Nicolaisen (2012) as well as in several other studies (e.g. National Audit Office (UK), 1988; Flyvbjerg et al., 2005; Parthasarathi and Levinson, 2010; Welde and Odeck, 2011). Interestingly, the conception of traffic forecasts for the approved alternative as being often underestimated is especially pronounced among politicians (61%), whereas researchers and consultants tend to consider the forecasts to be overestimated (25 %) rather than underestimated (18 %). Apparently, the politicians' opinions on this issue are more in line with state-of-the-art research than those among researchers and consultants developing and using transport models.

We also asked the respondents to state the direction of inaccuracy, if any, of the traffic forecasts for the no-build (zero) alternatives. However, in this case, a large proportion of the respondents apparently found it difficult to state any opinion. Among the total sample, nearly three out of four (72 %) failed to give any answer to this question, compared to only 2 % for the corresponding question about the approved ('build') project alternative. The proportion of missing answers was high among all groups of respondents, varying from 61 % among civil servants and clients to 80 % among politicians. Moreover, among those who did state an opinion, the proportion who considered forecasts for the zero alternatives to be mostly underestimated was five times as high as the proportion considering such forecasts to be most often overestimated. Apparently, the level of reflection about forecasts for the 'no-build' alternatives is not very high, and among those who do reflect on this issue, the assumptions about the direction of forecasting inaccuracy is largely out of phase with the inaccuracies demonstrated empirically by, for example, Nicolaisen (2012) (who found traffic in the 'no-build' alternatives to be overestimated by 7 % on average) and discussed theoretically by Næss (2011).

The respondents were also asked to state whether or not they agreed in the claim that traffic forecasts usually exaggerate the risk of congestion if no new infrastructure is built. The respondents had divided opinions on this issue, but a slight majority (40 % compared to 36 %) expressed full or partial support of the claim, with somewhat stronger support among researchers and somewhat greater disagreement among politicians.

Several among the interviewees recognize that model-based traffic forecasts are encumbered with uncertainties. In particular, the difficulty of predicting the (general) traffic growth is pointed at by a high number of interviewees.

Some interviewees also mention neglect of induced traffic as a shortcoming. Referring to the transport model used for several rounds of Environmental Impact Assessments for a proposed third crossing over the Limfjord sound in the outskirts of Aalborg, a transport planner and modeller explicitly states that the model used for these analyses ignored induced traffic:

The OD [origin-destination] matrix is not affected by accessibility. That's one of the things you could criticize about the model we use [...] If you make things more accessible, then that generates more traffic. It has always been like that. It also goes the other way; if you get more congestion, then that generates less traffic due to more resistance. And that is not reflected. ... (Model developer/Consultant, Denmark, in interview June 2010)

Here, it is clearly stated that the model used for the Limfjord forecasts does not include induced traffic. This is, however, not because the interviewee does not accept induced traffic as a real phenomenon. In his opinion, new models ought to include such effects. On the other hand, this

interviewee seems to consider induced traffic as something that should only be included in a sensitivity analysis (or robustness analysis, as he states it). This would imply that the main results communicated from the analysis would still be those without induced traffic included, since the purpose of a sensitivity analysis is normally to illuminate how the results are affected if the calculations are based on presuppositions other than those forming the base of the main analysis.

In some of the later assessments of Danish road infrastructure projects, attempts have been made to include induced traffic in the analyses. In cases where this is not incorporated in the model, an amount of induced traffic can be added by manually raising the values of the origin-destination matrix applying a certain elasticity, as illustrated by this comment from a model developer/consultant about the possibilities to incorporate induced traffic in a traffic model where this is not dealt with at the outset:

You can [include induced demand in the model], but then it is something you do manually when you have some specific solutions. And then you can say: What impact do we then think the elasticity would have made? And then we can increase our OD matrix with that figure, and things like that. (Model developer/Consultant, Denmark, in interview June 2010)

Such an adjustment was, however, not carried out in the case referred to by this interviewee. Other interviewees emphasize that the magnitude of adjustments like this is based on highly uncertain judgments (see Næss and Strand, 2012 for a discussion of the latter issue).

As could be seen from the questionnaire survey, few respondents believed that there was any tendency for forecasts for the zero (no-build) alternatives to be overestimated – the respondents rather thought that such forecasts tended to be underestimated, despite empirical evidence suggesting otherwise (Nicolaisen, 2012). Some of the interviewees do, however, illustrate how neglect of induced traffic is likely to result in overestimated forecasts for future traffic volumes in the absence of the proposed road scheme, thus supporting theoretical work on this issue (Næss and Andersen, 2010; Næss, 2011). A chief consultant in the Danish Road Directorate puts it this way:

Actually, when we make the projection we have already included the induced demand. Otherwise there would be a negative effect, right? I mean, if we don't expand it, then there is no room for traffic to grow. And then it cannot possibly reach the figures that the [national] forecasts we use to estimate growth indicate. But if we expand it, then we get the growth we expect. (Chief consultant in the Danish Road Directorate, in interview September 2010.)

Judged from the interviews, the input variable most prone to be subject to arbitrary choice is the annual traffic growth rate. Choosing a high or a low percentage of assumed annual traffic growth will influence the time at which congestion has grown to a level necessitating capacity increase. If the politicians want to argue that it is urgent to get funding for a given road building scheme in a heavily trafficked corridor, more weight may be added to the argument if the forecasts depict the situation as one where traffic growth will cause almost intolerable congestion in a few years unless additional road capacity is added.

3.3 'Predict and provide' as a tacit underlying assumption

The questionnaire survey shows that the professionals and politicians involved in developing and using traffic forecasts generally accept the phenomenon of induced traffic as a real phenomenon (cf. Table 1). Among the total sample, 77 % wholly or partly agree in the statement that expansion of road capacity in congested areas results in an overall increase in traffic, while only 11 % wholly or partly disagree. The proportions expressing full or partial agreement are especially high among researchers and consultants (88% and 89 %, respectively), but also among politicians there is a majority who wholly or partially agree (65 %). These figures are in line with the findings of Andersen (2013), who has documented that induced traffic has been acknowledged as an important and relevant phenomenon in traffic forecasting in a Danish context for more than eight decades.

A premise of the above-mentioned argument that new road capacity must be added in order to prevent forecasted traffic growth from causing intolerable congestion is that traffic should flow as freely as possible, and that congestion will not in itself slow down or stop further traffic growth and thereby prevent congestion from reaching an intolerable level. Instead, capacity should be added to allow for traffic to grow at a rate reflecting the observed or latent demand in the transportation market. These assumptions are often associated with what has been termed the 'predict and provide' paradigm (Owens, 1995), cf. Section 1.

According to one of our most experienced interviewees, who had been working as a traffic modeller since the 1960s, 'many traffic model calculations have over the course of time been conducted primarily in order to establish the need for future road capacity' (Traffic modeller and consultant, now retired, in follow-up e-mail communication July 2013 after interview in the spring of 2012). The following quote by a civil servant of the Danish Road Directorate clearly indicates the prevalence of this paradigm also in contemporary Danish transport policy:

What they [the politicians] care about is whether there are queues in the system. Then they think we need an expansion here. (Civil servant in the Danish Road Directorate, in interview September 2010.)

In situations of congestion, the main decision-making question within this paradigm will hence not be whether or not to increase road capacity, but rather where it should be expanded and when. In this perspective, the issue of induced traffic may not be perceived to be very important, since the amount of traffic induced by a new road scheme will usually not differ much between the alternative layouts. The following statement is illustrative:

Then you may well use a traffic model that is not as top-tuned as it ought to be. But since the same model is used to analyse all four [alternatives], some of its errors will be eliminated when comparing across. (Model developer/Consultant, Denmark, in interview June 2010.)

The alternatives referred to here are the different road building alternatives, not including the 'no-build' option. The fact that the errors are not insignificant when comparing road building with non-building is not commented on by the interviewee. Although the same interviewee admitted that it was possible to adjust for induced traffic 'manually' by raising the sum values of the origin-destination matrix (cf. an earlier quote), this was not done in the case in question. Seemingly, the solution to the forecasted capacity problem was framed around road capacity enlargements. Politically, and probably also among the planners, the dominant opinion is that we need to expand the capacity (see, e.g. Barfoed, 2009; Ehrenreich, 2013; Region Nordjylland, 2013). Otherwise, future traffic growth will not be accommodated in a satisfactory way.

A horizon of understanding where traffic growth is seen as inevitable and something to be accommodated can be an important reason why modellers, consultants and planners consider traffic models to be helpful decision-making tools even if the models are unable to take induced traffic into due consideration. The following statement by a model developer and consultant is illustrative:

There are some capacity limits around in the city – for example in the motorway tunnel. We're talking about system lifetime [before capacity is exceeded] ... Politicians cannot grasp traffic models. What they can understand are some assessments of when traffic will 'sand up'. Well, if traffic turns up not to increase by the forecasted 2 % annually with 2% the tunnel would have a lifetime until 2022. If it increased by 3% it would only be until 2015. Or with 1% it would be until 2030. (Model developer/Consultant, Denmark, in interview June 2010)

Here, the interviewee first says that traffic model forecasts must be 'translated' into statements about the remaining lifetime of the existing capacity of the road system, for example a motorway tunnel, in order to be meaningful for politicians. The question is how many years it will take until traffic on the stretch in question will 'sand up'. The tacit presupposition here is that the capacity will have to be expanded before that time in order to avoid the 'sanded-up' situation, which is clearly considered undesirable. The interviewee's use of the term 'lifetime of the tunnel' is based on the implicit presupposition that it is necessary to secure some level of free-flowing traffic. If

the free flow is obstructed (i.e. the tunnel has become 'sanded up'), then the lifetime of the tunnel has expired.

Moreover, the entire idea that traffic on the existing network will grow to a level where congestion evolves into a 'sanded-up' situation is based on the assumption that traffic (on the relevant road/in the corridor) will continue to grow also when the capacity limit is being approached. Such an understanding forms an important pillar of the conception that capacity increase is necessary and is thus closely associated with the 'predict and provide' paradigm. The neglect of the deterrent effect of congestion on further traffic growth at the same time reveals a limited understanding of the phenomenon of induced traffic. The way in which the general traffic growth is taken as an external input, common to the zero and the build alternatives, with forecasts pointing toward capacity increase as the 'natural' policy, is maybe even more outspoken in the following quote:

Well, overall you started making some forecasts of expected traffic volumes. And you didn't really use the model for that purpose. Because what it was all about was that there would be an overload on the existing connections with the forecasted traffic volumes. (University teacher and modeller in consultancy firm, Denmark, interviewed October 2010.)

The 'predict and provide' paradigm has as its ideal a frictionless transport system. Within such a horizon, the suppression of travel demand is not considered acceptable. Latent demand can then be used as an argument for road expansion since it will release suppressed demand. In a historical Danish context, this has been an explicit argument in support of urban road capacity increases (Stadsingeniørens Direktorat, 1967). This might seem contradictory to our statement above that omitting of induced traffic in forecasting is accepted under the 'predict and provide' paradigm because the policy question is which layout alternative of a proposed project to choose, rather than whether to build the project. However, given contemporary policy objectives of limiting the growth in urban motoring, advocating new urban road schemes on the ground of their likely traffic-increasing effects will probably not be considered very appropriate, since this might draw attention to the conflict between the 'predict and provide' approach and adopted policy goals of sustainable mobility.

If it is not shown explicitly in the analyses that proposed urban road projects are likely to lead to traffic growth, decision-makers will not be confronted with these inconsistencies. Together with the technical challenges of representing induced traffic correctly in transport models, this implies that there is a lack of any strong incentive for including induced traffic in the forecasts, at least as long as the provision of capacity to meet latent demand is seen as generally desirable. A member of the Danish parliament comments as follows on the gap between environmental objectives and the predict-and-provide policies actually pursued:

I think some politicians are quite aware that this is something you should not be too curious about, because then you might be faced with the need to make a choice. (Member of the Danish Parliament, in interview January 2011.)

4. Discussion and concluding remarks

Despite having been understood theoretically for more than 150 years and demonstrated empirically in numerous studies since the 1930s, the traffic-increasing effect of transport infrastructure construction is often neglected or severely underestimated in transport planning. Technical difficulties are sometimes mentioned as reasons for non-inclusion of induced traffic in transport modelling. It is, however, possible to include induced traffic in traffic models (SACTRA, 1994; Litman, 2012). If induced traffic had been recognized as an important issue, it seems reasonable to assume that such models would have been much more commonly used. Moreover, a vast majority of the survey respondents as well as the interviewees recognize the

existence of induced traffic as an empirical phenomenon. Lack of knowledge about induced traffic is therefore hardly the explanation of its exclusion from model-based traffic forecasting.

The present study thus suggests that an important reason for omitting induced traffic is that the effect is considered unimportant, since the policy question is not whether to build a new road scheme, but which suggested alternative to build. Since induced traffic is usually not differing so much between the different 'build'-alternatives, the error caused by omission of induced traffic in the models may then be considered negligible. This way of framing the decision problem is often associated with what has been termed the 'predict and provide' paradigm.

Some interviewees, while recognizing induced traffic as a real phenomenon, consider its magnitude to be small, in line with the explanation given by Noland and Lem (2002). However, this conception of induced traffic as a much more limited phenomenon geographically (only existing in the largest cities) and topically (confined to changes in trip frequencies but not including changes in modal split or trip length) than depicted in the academic literature is arguably linked to a horizon of understanding where what is at stake is not whether to expand road capacity but which road-building scheme to choose. If the former question was a serious concern, it seems likely that the modellers would keep themselves much more updated on the research literature on induced traffic and not conflate, for example, the concepts of induced traffic and induced travel (which is what is done when the modal shift component of induced traffic is ignored), or conflating induced travel with induced trip frequency (which is what is done when effects in terms of increased distances between origins and destinations are ignored).

Similarly, if the question of whether or not to build a proposed road was at the core, the additional costs of using a model enabling the planners to compare the impacts of 'build' with those of 'not build' in an appropriate way would hardly be considered prohibitive. There are apparently linkages between considering the inclusion of induced traffic in the models too costly, unnecessary because induced traffic is assumed to be negligible, or irrelevant to the choice between different routings of a proposed road.

Our findings are in line with those of Ladd (2012), who attributes the frequent neglect of induced traffic to the fact that it posed an inconvenient complication to a consensus that had emerged among transport planners in the USA during the first part of the 20th century. This consensus embraced mobility by car and entailed a commitment to construct more road space as long as traffic grew to fill it. Ladd thus makes an explicit link between denial or neglect of induced traffic and what later came to be known as the 'predict and provide' paradigm.

Some interviewees depict omission of induced traffic as a sort of precaution in order to avoid exaggerating the benefits from travel time saving in the economic project evaluation. However, forecasts ignoring induced traffic tend to systematically underestimate adverse traffic-related environmental effects, and in congested regions they are also likely to severely exaggerate time-saving benefits from road construction. In a situation where the adopted transport policy goals in many European countries have abandoned the 'predict and provide' paradigm, forecasting models ignoring the traffic-increasing effect of road capacity expansion in congested areas should also be avoided.

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Appendix A: Interpretation scheme for interview analyses

For each interviewee, the table shows brief answers to each of five research questions underlying the analysis of this article, based on our interpretation of the transcripts⁶

	What does the interviewee conceive to be the purpose of transport modelling?	What is the opinion of the interviewee about shortcomings in transport models?	How is induced traffic actually dealt with in the models with which the interviewee is familiar?	What does the interviewee think are the reasons for any lack of adequate dealing with induced traffic in transport models?	How important does the interviewee think any lack of adequate dealing with induced traffic is in transport models?
Model developer/ Consultant, Denmark, interviewed June 2010	'What if' / robustness analyses Basis for decision Calculate the 'remaining lifetime' of existing capacity Calculate environmental impacts	Uncertainty of general traffic development Cannot calculate for shorter periods than hours and thus poor at identifying peak-period problems Unrealistic traffic assignment at micro level – capacity limits ignored	Induced traffic is not included in the models	Detailed specifications are technically difficult and expensive Difficult to change an existing model Problems with data input And it requires theoretical knowledge about elasticities	Not very important - induced traffic is small compared to the difference between alternative general growth rates Errors will be similar across alternatives and are therefore not important for cross-comparison
Project director in consultancy firm, Denmark, interviewed July 2010	Illuminate impacts of making changes in a network Compare alternatives Objective analyses based on methods acceptable to different stakeholders Input to cost-benefit analysis Illuminate the robustness of the main conclusions to changes in key input variables	They have limitations and uncertainties, but are 'the best among evils' High uncertainty about general traffic growth Forecasting errors are usually due to incorrect assumptions about general traffic growth, and sometimes also errors in other input data (e. g. ferry fares for trucks)	Usually not included, except for a few large projects (e.g. Great Belt and other major new fixed links)	Economic constraints – analysis must be simplified to keep within the budget for the consultancy task	Not very important since he holds that induced traffic is small (both in terms of passenger km and modal split) and only occurs for the largest projects (but when pushed, he admits that it can be considerable for other projects too) His focus is on the redistribution of traffic from existing roads to the new scheme
Member of the Danish Parliament, interviewed January 2011	Provide a basis for arguments in support of an infrastructure project But also to show where we end up if current trends and policies are not changed – as a basis for choice between different policies To give the impression that transport policy decisions are	Forecasts easily become self-fulfilling prophecies But (before new capacity is added) forecasts sometimes overestimate traffic, like those for the Limfjord bridge Models are poor at capturing synergy effects Uncertainties are often not displayed and are anyhow ignored by politicians	Sometimes included, e.g. for the Fehmarn Belt	Impacts of traffic induced by improvements for competing modes may be omitted – and the omission not communicated – in order not to expose policy inconsistencies	Important, because environmental impacts are underestimated

⁶ N.A. indicates that the interviewee did not provide any information relevant to the question.

	objective and well-founded				
Model developer and civil servant in the Road Directorate, Denmark, interviewed September 2010	Enabling evaluation of the impact of some measure	Models are just approximations of reality Uncertain input data about growth in car ownership Aggregation at zone level hides important intra-zonal differences	The models developed by the Road Directorate since 2009 include induced traffic	Time pressure prevents post-opening evaluations as well as sufficient quality checks Consultants have too little knowledge about the models they use, and their clients usually do not pose critical questions (general statements not specifically referring to induced traffic)	Induced traffic in West Jutland is considered very insignificant, so in order to save resources this is ignored in modelling practice Predict and provide paradigm prevails in the highway directorate (but they have long ago acknowledged the existence of induced traffic)
Civil servant in the Ministry of Transport, Denmark, interviewed July 2011	Make traffic planners more aware about some causal relationships Provide input to economic analyses	Difficult/impossible to predict general traffic growth	Model unable to deal adequately with competition between rail and road Some speed reduction due to capacity restraint was tried manually (but not implemented in the main forecast?)	Technically difficult to include capacity restraints on road network It was considered more important to model the demand, and then later to assess whether and how the demand can be met Competition between rail and road considered unimportant (in the Køge Bugt case)	N. A.
University teacher and modeler in consultancy firm, Denmark, interviewed October 2010	To find the best location of a proposed new road link (Third Limfjord Crossing) and to identify how the existing road network would be relieved To influence the design of a scheme (e.g. light rail on separate lane)	Uncertainties increase as the model gets older Uncertainties undercommunicated due to political pressure The Aalborg model is a mere car traffic model Other models have added public transport and bike on this, but with poor results Cultural (and discursive) factors not included	The Aalborg model ignores induced traffic as well as the impact of parking availability	Economic constraints on what model improvements can be made – politicians decide on funding Since the purpose of modelling was to find the best road line alternative, the relationship between car and other modes was considered unimportant	N. A.
Project manager in public transport company, Denmark, interviewed May 2011	Overview of complex material that cannot be comprehended without calculations Compare the performance of different alternative line layouts Basis for decisions about large-scale infrastructure investments Input to the budgets of the	Inherent uncertainty in forecasts of general traffic development – and also model uncertainty (about the effects of endogenous variables, notably the amount of induced rail traffic created by the metro)	Generated metro travelling (and probably also induced public transport travel in general) is included in the modelling of the company. Previous forecasts were based on stated preferences, but they have now been updated with	N. A.	N. A.

	metro company		forecasts based on revealed preferences		
Project manager for a regional public transport project, Denmark, interviewed July 2010	Provide input for cost-benefit analysis and EIA Not very important for local political decision, but since Ministry of Finance requires CBA, modelling has to be done Analyze impacts of replacing full-length bus trips with combined bus and light rail trips Overview of complex transport system	Uncertainty about how the model deals with modal split and also about the distribution between regional and local buses Uncertainty about the 'light rail effect'	Generated light rail travelling (and probably also induced public transport travel in general) is included in the modelling of the Midttrafik company	N. A.	N. A.
Civil servant in the Traffic Agency, Denmark, interviewed May and September 2011	Estimation of passenger impacts of new route schedules (including impacts of new lines) Getting overview of the traffic within complex route configurations	Inaccurate input data Errors in the model (e.g. for the OTM-based Ring Rail forecast) Impacts of planned, but not yet adopted road projects in the same corridor are ignored. This may lead to exaggerated estimates of the amount of traffic induced (unless counterfactual thinking is applied)	Induced rail traffic is included in a very simplified way (a little more sophisticated in the model for Kbh-Ringsted)	N. A.	N. A.
Civil servant in the Road Directorate, Denmark, interviewed September 2010	N. A.	Difficult to forecast general traffic growth Induced traffic only included in some models Omission of induced traffic leading to overestimated traffic in the zero alternative	N. A.	Apart from some recent large projects (new fixed links like the Great Belt and Øresund), induced traffic has been considered insignificant	Not very important, since politicians want to expand capacity where there is congestion, without caring much about cost-benefit analyses. But if induced traffic is ignored, then the economic benefits of road projects tend to be underestimated
Previous municipal politician responsible for the technical sector, Denmark, interviewed December 2010	Input to cost-benefit analysis as a basis for prioritizing between different investments at a national scale	Model results are often reified and considered as truths, whereas they are in fact heavily dependent on the assumptions about its input variables and on what variables are included or excluded Inconsistency between assumptions of traffic models and assumptions on which other policies are based	N. A.	N. A.	Politicians know what they want to go in for, almost independently of what numbers the tables show [general statement, not referring particularly to induced traffic]
Transport	Provide	Black-box nature of	N. A.	N. A.	N. A.

model researcher, Sweden, interviewed October 2011	different stakeholder with objective information as a basis for their argumentation Sensitivity analyses of the impacts of changes in different input variables, e.g. petrol price	models - models are owned by agencies denying other people access to information about model assumptions			
Transport model researcher and consultant, Sweden, interviewed October 2011	N. A.	N. A.	N. A.	Unrealistic travel time assumptions for a proposed rail project caused exaggerated estimates of time savings and as a consequence exaggerated induced traffic for the railway. Could be due to optimism bias or even strategic misrepresentation	N. A.
Previous municipal politician responsible for the technical and environmental sector, Denmark, interviewed December 2010	Provide a basis for arguments in support of an infrastructure project	N. A.	N. A.	N. A.	N. A.
Retired traffic analyst, Denmark, interviewed January 2012	N. A.	N. A.	N. A.	N. A.	N. A.
Project analyst in consultancy firm, Denmark, interviewed June 2012	N. A.	N. A.	N. A.	N. A.	N. A.